BRL MR 2143

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AD736369

MEMORANDUM REPORT NO. 2143

WIND TUNNEL MAGNUS TESTING OF A CANTED FIN OR SELF-ROTATING CONFIGURATION

by

A. S. Platou

December 1971

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U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

19

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U.S. Army Aberdeen Research & Development Center Ballistic Research Laboratories Aberdeen Proving Ground, Maryland 21005	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

WIND TUNNEL MAGNUS TESTING OF A CANTED FIN OR SELF-ROTATING CONFIGURATION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Anders S. Platou

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1971	24	1

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. RDT&E 1T061102A33D	Memorandum Report No. 21[illegible]
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Army Materiel Command Washington, D. C.

13. ABSTRACT

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Magnus Forces						
Measuring Magnus Forces						

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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ASPlatou/lca
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LIST OF SYMBOLS

d	body diameter
m_p	yaw couple due to opposing forces $N \sin \varepsilon$ and N_p
p	spin in rad/sec
$C_{M_{CG}}$	$= \dfrac{\text{pitching moment about CG}}{\frac{1}{2}\rho u^2 Sd}$
C_n	measured yawing moment coefficient $= \dfrac{n}{1/2\ \rho u^2 Sd}$
C_N	normal force coefficient on the configuration $= \dfrac{N}{\frac{1}{2}\rho u^2 S}$
C_{N_p}	Magnus force coefficient $= \dfrac{N_p}{\frac{1}{2}\rho u^2 S \frac{pd}{u}}$
C_Y	measured side force coefficient
N	normal force
N_p	Magnus force
N_s	normal force due to an angle of yaw
Re	$\dfrac{\rho u}{\mu}$ = Reynolds number/ft.
S	cross-sectional body area $= \dfrac{\pi d^2}{4}$
α	indicated angle of attack
β	angle of yaw at zero indicated angle of attack
ε	angle of roll of true angle of attack plane
ρ	air density
ℓ	distance between $N \sin \varepsilon$ and N_p
ℓ_F	Magnus force C.P. to C.G. distance
ℓ_N	normal force C.P. to C.G. distance
u	air velocity

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I. INTRODUCTION

It has recently come to our attention that most Magnus wind tunnel measurements on canted fin or self-rotating configurations contain a normal force interaction term which cannot be corrected in the usual manner. The error involves the fact that it is very difficult to obtain side force and moment data on the configuration at zero spin. The model must contain a lock or other means to prevent rotation and at the same time permit reading the side force and moment strain gage bridges. The normal force interaction term can be sufficiently large, so that if not eliminated, it can completely mask the Magnus force and moment.

II. THE NORMAL FORCE INTERACTION ERROR

In order to explain the interaction error let us assume that we have a test section tunnel flow which is exactly horizontal and contains no variation of flow inclination or Mach number in the test region. Let us also assume that the strain gage balance has no interaction terms and that the normal force or pitching moment measuring plane is exactly vertical and that the side force and moment measuring plane is exactly horizontal. All appears to be ideal except for one item. When installed in the test section at zero indicated angle of attack, the model and balance are at an angle of yaw "β", Figure 1. The side force developed on the configuration at zero spin is then

$$N_s = C_{N_\alpha} \frac{1}{2} \rho u^2 \beta \frac{\pi d^2}{4} \tag{1}$$

or the true angle of attack plane can be considered as being horizontal even though the indicated angle of attack is zero. As the indicated angle of attack is changed the true angle of attack plane will rotate such that

$$\sin \epsilon = \frac{\tan \beta}{\sin \alpha} \tag{2}$$

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The normal force which acts in the true angle of attack plane will then have a component acting in the side force measuring direction such that $N_s = N \sin \varepsilon$. If one does not measure N_s at zero spin and at each angle of attack, its value is included in the data obtained while the model is spinning.

Normally, since the zero spin data are difficult or impossible to obtain on a self rotating configuration, experimenters have tended to present the results of the spinning data at angle of attack minus the spin data at zero angle of attack. These data still contain the normal force interaction term and really present the $\frac{pd}{u} C_{N_p} - C_N \sin \varepsilon$.

A striking example of this error is shown in reference 1*. The side force and moment acting on the canted fin configuration of reference 1 is presented in Figure 2. The force is negative at low angles of attack, but becomes positive above 6° angle of attack. The moment on the other hand is positive at low angles, remains positive as the force crosses over at 6° and does not become negative until higher angles are reached. The existence of a moment at zero force is indicative of a couple and can be explained as shown in Figure 3. The normal force interaction term ($N \sin \varepsilon$) acts at the normal force center of pressure while the Magnus force on the fins must act near the center of the fins. Therefore, the couple arm "ℓ" can be estimated and the angle ε determined from

$$\sin \varepsilon = \frac{m_p}{\ell N} \tag{3}$$

Using the data of Figure 2 and normal force and pitching moment data on this configuration obtained from F. Ragan in a private communication, it is possible to determine ε, β, and $C_Y - C_n \sin \varepsilon$ for each angle of attack. Originally the author had just computed ε and β for the case where the pure couple was present (i.e., $\alpha = 6°$). During the review of

* *References are listed on page 15*

this report, Dr. C. H. Murphy pointed out the possibility of doing this at each angle of attack.

$$C_Y = C_N \sin \varepsilon + C_{N_p} \frac{pd}{u} \cos \varepsilon \tag{4}$$

$$C_n = \ell_N C_N \sin \varepsilon + \ell_F C_{N_p} \frac{pd}{u} \cos \varepsilon \tag{5}$$

Above, it is assumed that the side force, C_Y, and the yawing moment, C_n, presented by Ragan are not divided by the spin. Combining (4) and (5):

$$\sin \varepsilon = \frac{C_n - \ell_F C_Y}{(\ell_N - \ell_F) C_N} = \frac{C_n - \ell_F C_Y}{\ell C_N} \tag{6}$$

For each angle of attack, equation (6) can be solved for ε by inserting the known values of C_n, C_Y and C_N while values of ℓ and ℓ_F can be estimated by assuming the Magnus force center of pressure is at the mid chord of the fins. The distance, ℓ_F, can be estimated in the reference 1 case, for only the fins are rotating and creating the Magnus force. The distance, ℓ_F, cannot be estimated in the case of a finned projectile where the body rotates. The values used are shown in Table 1 and the values of ε, β and $C_Y - C_N \sin \varepsilon$ computed from them.

It is seen that the value of β for this experiment is always less than one half degree. This indicates that the variation of flow inclination in the test region is very good, but it also indicates that the normal force interaction term N sin ε is very sensitive to changes in β. Therefore, the computed correction may still contain errors of fairly high magnitude. A more exact way of obtaining accurate Magnus data is to obtain the side forces and moments at zero spin.

III. CONCLUSIONS

Wind tunnel Magnus data obtained to date on canted fin configurations may be invalid in that a severe normal force interaction may be present. Although it may be possible in some cases to correct for this interaction, it is in general best to remove the interaction by subtracting the zero spin data at each angle of attack. This requires a system in which the model can be kept at zero spin during an angle of attack sweep of the configuration.

REFERENCES

1. F. J. Regan, "Magnus Measurements on a Freely Spinning Stabilizer," AIAA Paper No. 70-559, AIAA Atmospheric Flight Mechanics Conference, Arnold Engineering and Development Center, May 1970.

Table 1. Correction of the Data in Reference 1

α	0	1	2	3	4	5	6	7	8	9	10
C_n	0	.015	.030	.040	.050	.055	.057	.045	.028	.003	-.009
C_Y	0	-.001	-.002	-.004	-.004	-.001	0	+.004	.009	.018	.022
ℓ_F	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31
C_N	-.20	+.035	.090	.150	.225	.300	.385	.485	.585	.690	.810
$C_{M_{CG}}$	+.005	.010	.010	0	-.035	-.115	-.210	-.310	-.445	-.600	-.735
ℓ_N	.7	+1.05	+.38	0	-.54	-1.34	-1.91	-2.24	-2.66	-3.04	-3.18
ℓ	12.3	12.6	12	11.6	11.1	10.3	9.7	9.4	8.9	8.6	8.4
$\sin \varepsilon$		.143	.117	.107	.0885	.057	.0534	.0245	.0135	.0370	.0423
ε		8.2	6.7	6.2	5.1	3.3	3.1	1.4	.8	2.1	2.4
β		.14	.23	.32	.35	.28	.316	.17	.11	.33	.42

Solving equation (4) for $C_{N_p} \frac{pd}{u} \cos \varepsilon$

$C_N \sin \varepsilon$	.005	.011	.016	.020	.017	.0206	.012	.008	.025	.034
$C_Y - C_N \sin \varepsilon$	-.006	-.013	-.020	-.024	-.018	-.0206	-.008	+.001	-.007	-.012

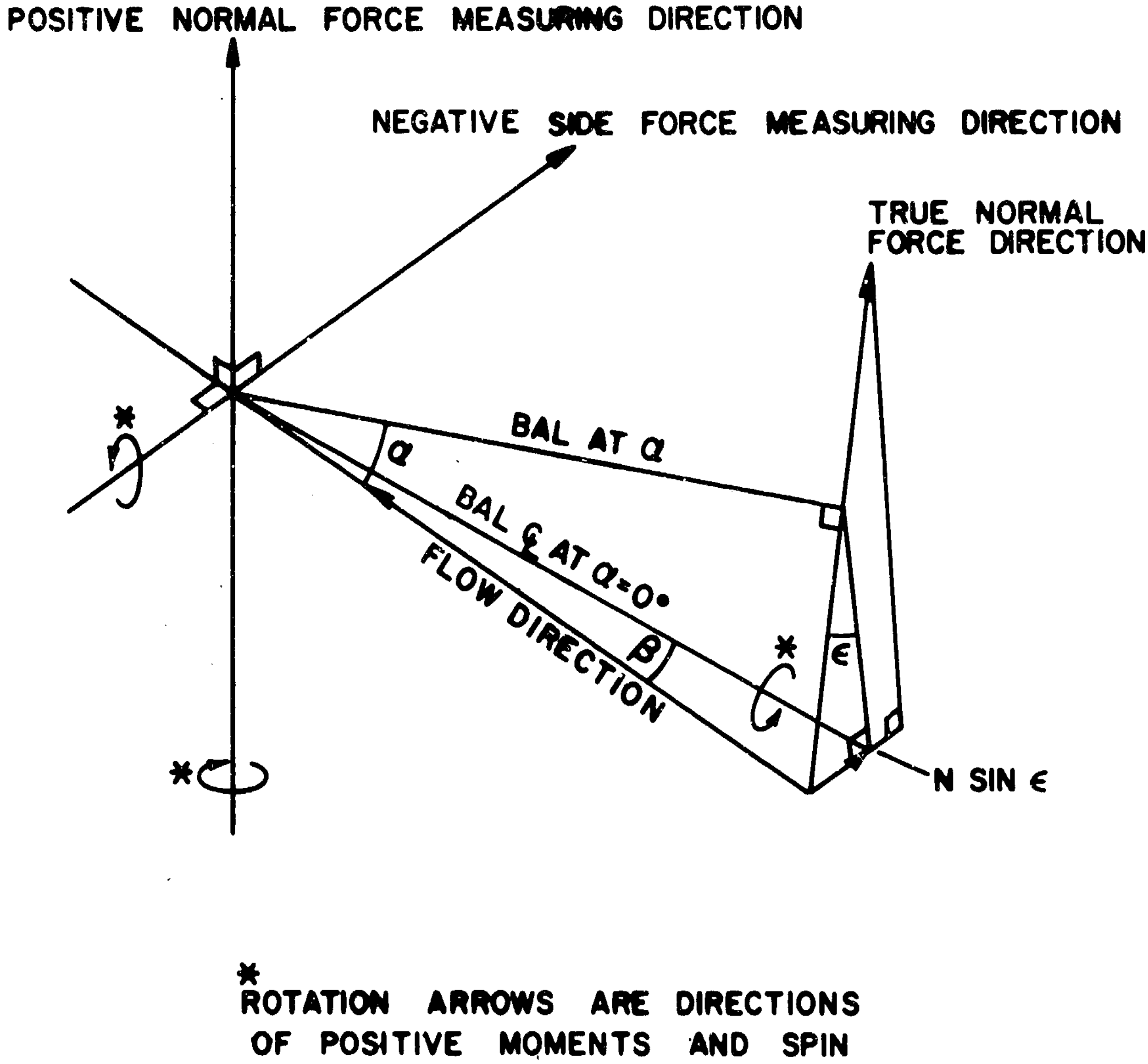

Figure 1. The Geometry Involved in Measuring Magnus Forces

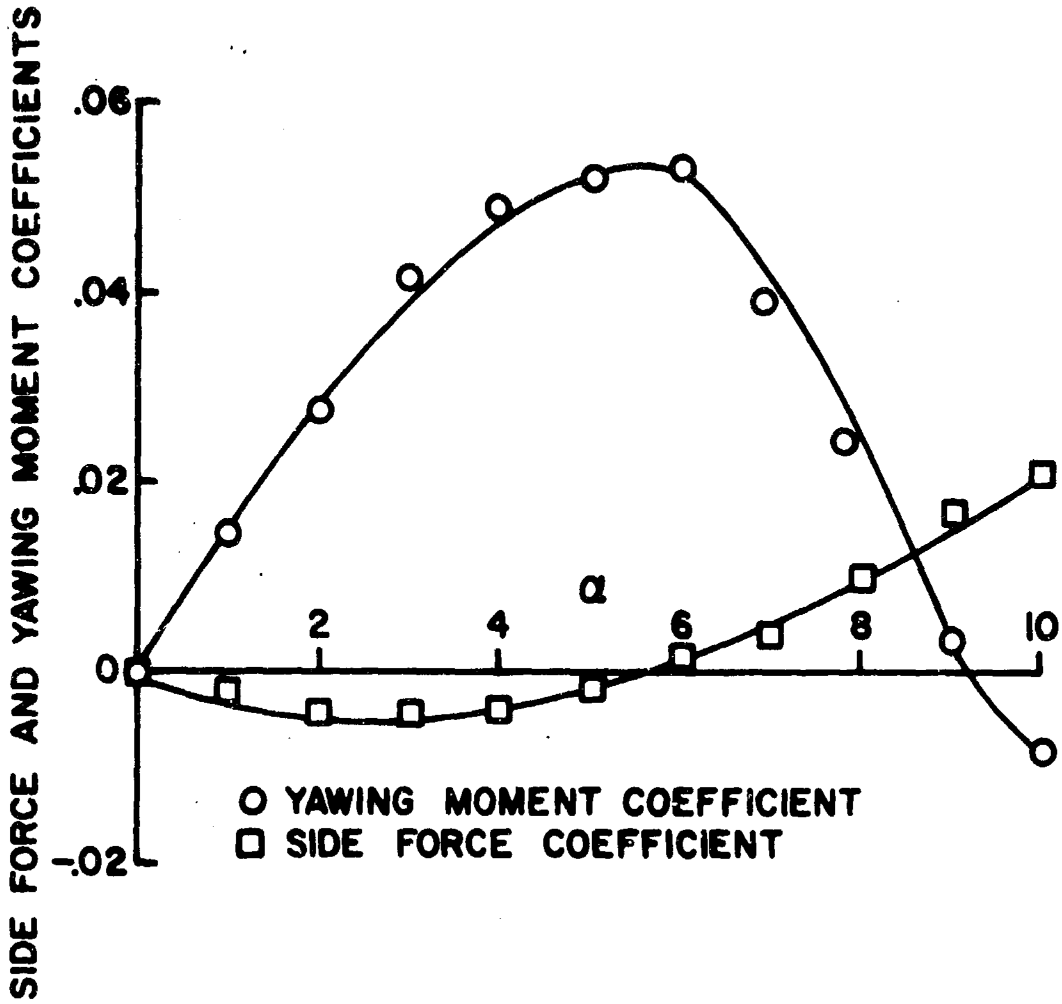

Figure 2. Side Force and Yawing Moment Coefficients Versus Angle of Attack for a 4° Fin Cant at Mach Number 0.90, Re = 1.5×10^6

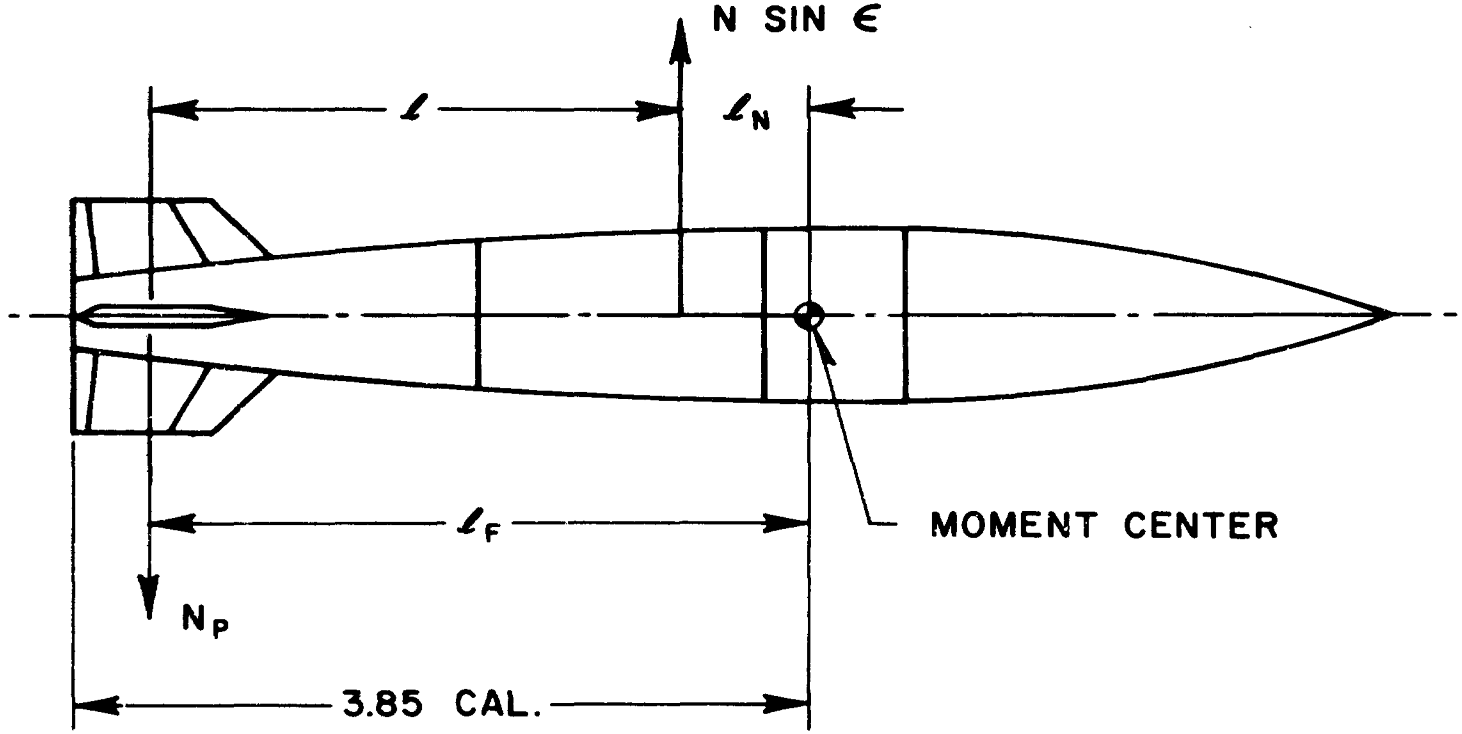

Figure 3. The Couple Created by Normal Force Interaction

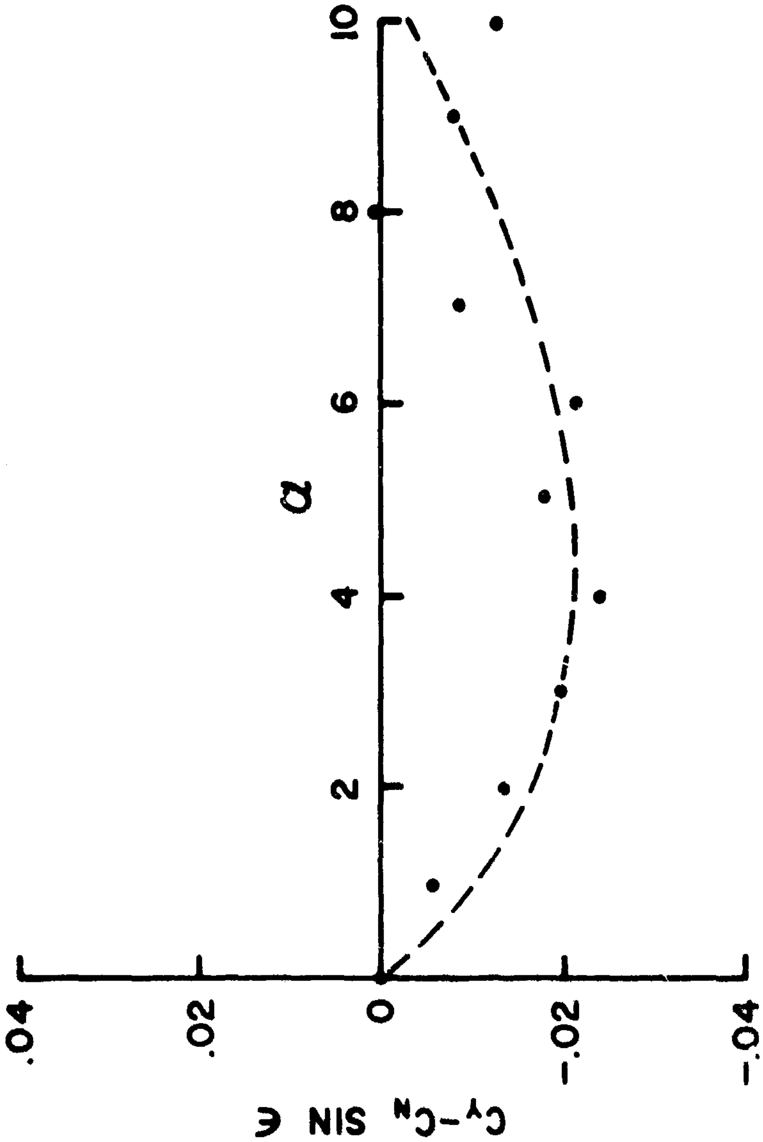

Figure 4. Figure 2 Corrected for Normal Force Interaction